Green Synthesized Metallic Nanoparticles Utilizing Indigenous Botanical Reducing Agents

Author-

Shibanjan Paul Roy

Assistant Professor of Swapna Devi College of Education

Abstract-

The process of preparing metallic nanoparticles from indigenous botanical extracts has been found to be more sustainable and environmentally friendly than other methods of synthesis. The current research deals with the study of plant based reducing agents like Azadirachta indica, Ocimum sanctum and Moringa oleifera in order to prepare silver, gold and zinc oxide nanoparticles. Plant chemicals such as polyphenols, flavonoids and terpenoids help in quick reduction and stabilization of nanoparticles without producing any toxic substances. The synthesized nanoparticles show characteristic features of uniform morphology, high stability and strong antimicrobial, antioxidant and catalytic properties when characterized through UV-Vis spectroscopy, XRD analysis, SEM micrographs and FTIR spectrophotometry.

Introduction-

Metallic nanoparticles exhibit distinct physicochemical characteristics which find various uses in medicine, agriculture and catalysis. Traditional methods require the use of hazardous substances, high energy requirements and harmful wastes. Green synthesis with locally available plant based reducers constitutes an environmentally friendly alternative. Native plants such as Azadirachta indica, Moringa oleifera and Ocimum sanctum produce compounds like polyphenols, flavonoids and terpenoids which act as reducers and stabilizers for metal ions without leaving any toxic byproducts. Green synthesis makes use of locally available biodiversity resources, is cost effective and environmentally sustainable. Native plants are site-specific, sustainable and culturally familiar. Understanding their phytomolecular constituents will not only make nanotechnology more environmentally friendly but also promote bioresource exploitation.

Materials and Methods-

1. Collecting and Authenticating Plant Material-

Fresh leaves, stems and root materials from indigenous plants Azadirachta indica, Ocimum sanctum, Moringa oleifera, Tinospora cordifolia and Emblica officinalis were collected. The plant samples were authenticated by me botanically. The plant material was washed with deionized water, dried in shades for 10-14 days, ground with a mechanical grinder and kept in sealed containers at 4°C.

2. Extraction of Plant Samples-

Plant sample powder (10g) was boiled in 100ml distilled water at 60oC for 30 minutes or soaked in 70% ethanol solution at room temperature for 48 hours. This mixture was filtered with Whatman No.1 filter paper and centrifuged at 5000 rpm for 15 minutes. The supernatant was collected and kept at 4oC for further use as reducing and stabilizing agent. The total content of phenol and flavonoids was estimated using Folin Ciocalteu reagent and aluminum chloride assay, respectively.

3. Green Synthesis of Metallic Nanoparticles -

For synthesis of silver nanoparticles, 10 mL of extract was drop-wise added to 90 mL of 1 mM $AgNO_3$ under continuous stirring at 60°C. The dark brown color of the solution showed formation of the particles. For gold nanoparticles, 5 mL of the extract was mixed with 95 mL of 1 mM $HAuCl_4$ under pH 7.0 and temperature 80°C. For zinc oxide nanoparticles, the 0.1 M of $Zn(NO_3)_2$ was used along with the extract at pH 12 and then calcinated at 400°C for 2 hours.

4. Physicochemical Analysis-

Surface Plasmon Resonance studies were carried out via UV-visible spectroscopy over the wavelength range of 200 to 800 nm. Crystallinity and Phase analysis were conducted via X-ray diffraction analysis with Cu-Kα radiation at $2\theta=20–80°$. Microstructure and particle sizes were evaluated using Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM). Element analysis was performed using Energy Dispersive Spectroscopy. Particle size distribution and zeta potential were evaluated using Dynamic Light Scattering Technique. The functional groups involved in reduction and capping were characterized using FTIR spectroscopy ranging from 4000 to 400 cm^{-1}.

5. Assessment of Stability and Yield –

The stability of the nanoparticles was tested in aqueous solutions ranging pH 3 to 11 and NaCl levels 0 to 500 mM for 30 days. The absorbance was measured at λ

max weekly. The yield was determined by weighing dry nanoparticles obtained after centrifuging at 15000 rpm for 30 minutes and lyophilization.

6. Biological Activity Protocols-

Antimicrobial activity was determined against E. coli, S. aureus and C. albicans using agar well diffusion and microbroth dilution method for determination of MIC. Antioxidant activity was studied using DPPH, ABTS and FRAP methods. Cytotoxic activity was assessed on L929 fibroblasts using MTT assay from 10 to 200 µg/mL for 24 hours. The catalytic activity was assessed by the reduction of 4-nitrophenol to 4-aminophenol by $NaBH_4$ monitored at 400 nm.

7. Data Analysis-

All experiments were done in triplicates. Results were reported as mean ± SD. The statistical analysis was performed by using one way ANOVA followed by Tukey's multiple comparison test using SPSS version 26.0. The significance was considered at $p < 0.05$. Mechanism of action was proposed by correlating FTIR groups with reduction and nanoparticle stability studies.

Results and Discussion-

UV-Vis spectra confirmed silver, gold and zinc oxide nanoparticle formation at 420, 530 and 370 nm, respectively. XRD revealed crystalline fcc structures with average sizes of 15–40 nm. SEM and TEM showed spherical to quasi-spherical morphology. FTIR identified polyphenols and flavonoids as capping agents, enhancing colloidal stability for 30 days. Moringa oleifera extract yielded smallest particles and highest zeta potential, -32 mV. Nanoparticles exhibited strong antimicrobial activity against E. coli and S. aureus, MIC 12.5–50 µg/mL. Antioxidant assays showed 78–92% DPPH scavenging. Cytotoxicity remained low up to 100 µg/mL. Indigenous extracts thus enable stable, bioactive nanoparticles suitable for biomedical and agricultural applications.

Conclusion-

Green synthesis using indigenous botanical reducing agents produced stable, bioactive metallic nanoparticles with uniform morphology. Phytochemicals enabled eco-friendly reduction and capping, eliminating toxic waste. The nanoparticles demonstrated potent antimicrobial and antioxidant properties. This sustainable approach supports low-cost, scalable nanotechnology applications in medicine, agriculture and environmental remediation.

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